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Report: Electromagnetic Radiation (EMR) assessment for Space Operation New Zealand Limited Awarua Earth Station

Table of Contents

1 Background 3

1.1 Antenna locations and configurations 3

2 Relevant Regulations/Standards 3

2.1 General Public exposure to EMR 3

2.2 Occupational exposure to EMR 4

3 Procedures for EMR exposure assessment 4

4 Predicted EMR Levels 5

4.1 Calculation Method 6

4.2 Power Summation from other antennas in the Array 6

5 Public and Occupational Access to Antennas 7

5.1 On Site 7

5.2 Away from Site 7

6 Recommendations 9

6.1 Other considerations 10

7 Appendix A: Site Antenna information 11

8 Appendix B: General Public Exposure Zones for Awarua SES 11

9 Appendix C: Occupational Exposure Zones for Awarua SES 11

10 Appendix D: EMR Calculations 12

10.1 VHF Crossed Yagi: Kepler 13

10.2 450MHz Crossed Yagi: Planet-1A/2A/2B/2C 14

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10.3 900MHz Crossed yagi: AWA-3 (Swarm) 15

10.4 Omni: Swarm1/2/5 16

10.5 Patch: Swarm3/4 17

10.6 S Band: AWA-1/AWA-4/KSAT-1 (SpaceX)/KSAT-2/KSAT-3/KSAT-4/Leaf-1/Planet-1/Planet-2/Spaceflight-1 18

10.7 S Band: Spire-1 19

10.8 C Band: GlobalStar-1/2/3 20

10.9 Ku Band: Kepler 21

10.10 Ka Band: Starlink 22

10.11 Uncertainty of the RF field assessment (Appendix D of AS/NZS 2772:2:2016 23

11 Appendix E: References 24

1 Background

Space Operations New Zealand Limited owns and operates a satellite earth station at Awarua which comprises of a large number of antennas for communicating with Non Geostationary Orbit (NGSO) satellites. This report summarises the results and conclusions from analysing the non-ionising electromagnetic field radiated by the antennas used at this site.

1.1 Antenna locations and configurations

The description and .location of the antennas can be found in Appendix A and aerial photograph showing the locations in Appendix B.

2 Relevant Regulations/Standards

2.1 General Public exposure to EMR

Paragraph 55 of Resource Management (National Environmental Standards for Telecommunications Facilities) Regulations 2016 (NESTF) provides a standard for the maximum acceptable level of public exposure to electromagnetic radio frequency fields, and states that a telecommunication facility is a permitted activity as far as radiofrequency fields are concerned if the telecommunication facility is operated in accordance with NZS 2772: Part 1:1999 Radiofrequency Part 1 - Maximum Exposure Levels - 3kHz to 300GHz. The limits in NZS 2772: Part 1:1999 vary with frequency i.e.

Frequency (f)	Power Flux Density(PFD) (W/m^2)
10MHz to 400MHz	2
400MHz to 2000MHz	f/200
2GHz to 300GHz	10

Table 1: Maximum General Public Exposure Power Density Limits versus Frequency

General population/uncontrolled exposure applies to situations in which the general public may be exposed, or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure, or cannot exercise control over their exposure. It is these considerations that underlie the more stringent exposure limits for the general public when compared with the occupation limits given below.

Additionally the NESTF also states that if the radio frequency fields are predicted to reach or exceed 25% of the maximum level in NZS 2772: Part 1 at places reasonably accessible to the general public, the operator must submit a post—commencement report to the local authority within three months of commencement of service providing evidence that the actual radiofrequency field levels comply with NZS 2772:Part 1.

2.2 Occupational exposure to EMR

NZS 2772 Part 1 also gives maximum exposure levels for occupational workers i.e.

Frequency (f)	Power Flux Density(PFD) (W/m^2)
10MHz to 400MHz	10
400MHz to 2000MHz	f/40
2GHz to 300GHz	50

Table 2: Maximum Occupational Exposure Power Density Limits versus Frequency

Controlled/occupational exposure applies to situations where persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure. Occupational/controlled exposure also applies where the exposure is of transient nature as a result of incidental passage through a location where the exposure limits may be above the general population/uncontrolled limits, as long as the exposed person has been made fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area or by some other appropriate means

3 Procedures for EMR exposure assessment

(Ref Rec. ITU-T K.52 (06/2021))

If it is determined that an EMF exposure assessment is needed due to the presence of intentional emitters, it should be performed for all locations where people might be exposed to EMF. The intent of the assessment is to classify potential exposure to EMF as belonging to one of the three following zones:

1. **Compliance zone**: In the compliance zone, potential exposure to EMF is below the applicable limits for both controlled/occupational exposure and uncontrolled/general public exposure.
2. **Occupational zone**: In the occupational zone, potential exposure to EMF is below the applicable limits for controlled/occupational exposure but exceeds the applicable limits for uncontrolled/general public exposure.
3. **Exceedance zone**: In the exceedance zone, potential exposure to EMF exceeds the applicable limits for both controlled/occupational exposure and uncontrolled/general public exposure.

For many installations, the exceedance zone and the occupational zone are not accessible to people, or are only accessible under unusual circumstances, such as a person standing directly in front of the antenna.

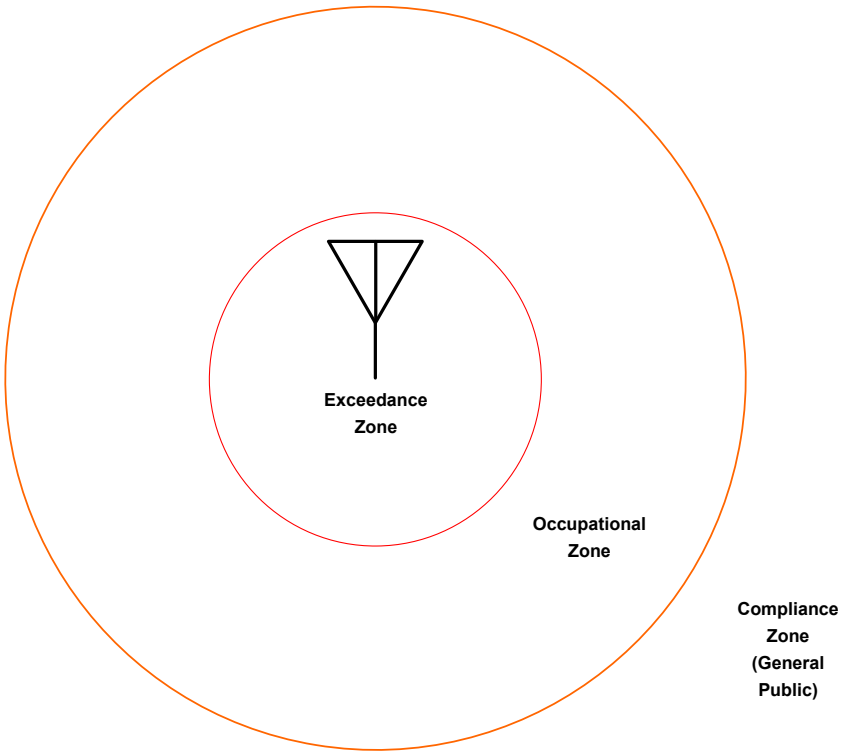

Figure 1: illustration of exposure zones

4 Predicted EMR Levels

(See the calculations results in Appendix C)

Assessment of EMR levels are based on calculated predictions instead of measurements because for this site making measurements will be time consuming and complex. Since predictions are not as accurate as measurement then the compliance (general public) and occupational zone limits used in this assessment are based on 25% of their respective maximum exposure limits i.e.

Frequency (f)	Power Flux Density(W/m^2)	
	25% GPEL	25% OEL
10MHz to 400MHz	0.5	2.5
400MHz to 2000MHz	f/800	f/160
2GHz to 300GHz	2.5	12.5

Table 3: 25% Maximum Exposure Limits

Calculations based on this exposure limits will be conservative as they assume that the antenna is stationary (for those that are tracking) and at its minimum allowable elevation angle which is the worse-case for ground based exposure.

The exposure limits are based on averaged 6 minute values so given the elevation and azimuth angle of the antenna will change during tracking of a satellite reducing the exposure PFD below the worst-case then the time averaged exposure PFD will be less than the worst-case.

4.1 Calculation Method

4.1.1 Parabolic and Yagi Antennas

With the exception of the Swarm omnidirectional and patch antennas, all EMR exposure calculations have been done for person standing on the ground adjacent to the antenna and the graphs shows how the ratio of the predicted Power Flux Density (PFD) to the General Public Exposure Limit (GPEL) varies as distance along the ground increases from the antenna. The orange line is the ratio for 25% of the GPEL and the red line is the ratio for 25% of the Occupational Exposure Limit. (GPEL).

The distances considered for the parabolic antennas are in the Near Field region and figures 2 & 3 of reference 1 (Appendix D) have been used to calculate the off axis PFD. For the VHF and UHF Yagi antennas the distances are in the Far Field region and hence the antenna radiation patterns have been used to calculate the PFD. For the yagis typical radiation pattern envelopes (RPE) for a given number of elements have been used.

The distances away from the antenna are reference to the phase centre for the antenna. In the case of parabolic antennas this from the front edge of the reflector but in the case of Yagi antennas this not easily determined but for this report has been assumed to be midway between the reflector and most forward director element.

4.1.2 Omnidirectional and Patch Antennas

For the Swarm omnidirectional and patch antennas the worst case on axis PFD have been calculated.

4.1.3 Prediction Uncertainty

Using the methods given above and Appendix D of AS/NZS 2772:2:2016, the predicted expanded uncertainty is 2.5dB (see Appendix C). This is less than the 3dB allowance given for reference level assessment in Table 6.1 of AS/NZS 2772:2:2016 and hence compliance with 25% of GPEL has been demonstrated in any publicly accessible space.

4.2 Power Summation from other antennas in the Array

Power summation from microwave antennas need only to be considered in terms of the standard where the main radiation lobes from antennas intersect with other antennas. All the high gain antennas (parabolics and Yagi) are tracking Non Geostationary Orbit (NGSO) satellites which pass overhead quickly and hence there is a very low probability that two antennas or more will be pointing in the same direction (azimuth and elevation) at the same time. When this does occur it will be only for a short period of time given the speed of the satellites. This period will be less than the 6 minutes used for exposure limits (above) and hence the time averaged value given the relative distances between antennas will not be exceeded within the compliance and occupational zones determined by this report.

5 Public and Occupational Access to Antennas

5.1 On Site

The site map shows the compliance and occupational zones around each antenna. Note that the zones around the crossed yagi antennas are there to prevent the antenna elements from being touched rather than show the compliance zone. This is a precautionary approach as the calculations show that at 1m away from the antenna the predicted PD is still less than 25% of the GPEL.

Assuming a fence around the site to prevent accidental access then site map shows that the occupational zones are inside the site for all antennas.

5.1.1 S Band

The largest EMR exposure zones are for the S band antennas and hence to give a less conservative prediction of the EMR levels, the time averaged (6 min) exposure has been calculated based on antenna elevation angles as it tracks a satellite passing between horizons. The following worst-case low elevation pass has been used, the minimum elevation is 5 degrees and the maximum is 16 degrees.

Figure 2: S Band Low Elevation Pass

5.2 Away from Site

The site is surrounded by farmland and access roads with farm buildings at least 700m away. At this distance based on worst case antenna elevation angle of 5 degrees then a person would have to be at least 120m above ground to intercept any antenna beams. Therefore anyone working at this farm building will exposed to levels much less than the GPEL.

The predicted EMR graphs show the exposure level rapidly falls within distance and hence standing outside the site will be exposed to levels much less than the GPEL. There is, however, the potential for a person to be exposed to higher EMR levels if they elevated above the ground when working on or driving farm machinery adjacent to the site. For example if someone is outside the site working in the paddock adjacent to and 30m away from the Planet-1 antenna, and standing 2m above the ground then it possible to be exposed to levels close to the GPEL. The exposure period will be short given antenna scanning and hence the 6 minute time average exposure value should be used reducing the exposure value below the GPEL for this case.

6 Recommendations

1. For those regions where the exposure exceed the occupation limit, physically define demarcation zone (red circle on site map) by installing plastic bollards and chain around antenna with the following warning signs attached.

2. For perimeter fence around site ensure it at least 2m high and difficult to climb. Attach the following warning sign:

3. For all those working and visiting the site, a site induction process to be completed by all those working and visiting the site.
4. Close supervision of all visitors to site so that they do not enter any exceedance zones around antennas.
5. Training in EMR awareness for all staff working on site including knowledge and understanding of the work practices necessary to keep them safe while working around antennas.
6. Procedures for using elevated platforms while on site to avoid EMR exposure exceeding the maximum OEL.

7. Procedures for turning off transmitters before exceedance zones and some form of fail-safe interlocking to ensure that transmitters are not accidentally turned on while staff are working in this zone around an antenna.

8. When an antenna is operational and in use there must be some form of limit switch to ensure that that transmitter is turned off when tracking antenna elevation is less than the operational minimum.
   Note: This what has been used for calculating the EMR exposure levels.

9. Regular review of procedures.

6.1 Other considerations

6.1.1 Medical aids and implants

Metallic implants and other medical devices can be susceptible to RF interference and therefore any staff or visitor should with them be monitored closely when entering occupation zones for negative reactions.

6.1.2 Pregnancy

(ref NZS 2772: Part 1)

A pregnant woman should not be exposed to levels of RF fields above the limits of public exposure. Whilst there is no clear evidence that RF is harmful to the foetus there are differing results in the literature and more research is needed.

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7 Appendix A: Site Antenna information

See attached file: Awarua Antenna Locations List 20221008

8 Appendix B: General Public Exposure Zones for Awarua SES

See attached file: Awarua SES Site Layout GPEL Zones

9 Appendix C: Occupational Exposure Zones for Awarua SES

See attached file: Awarua SES Site Layout OEL Zones

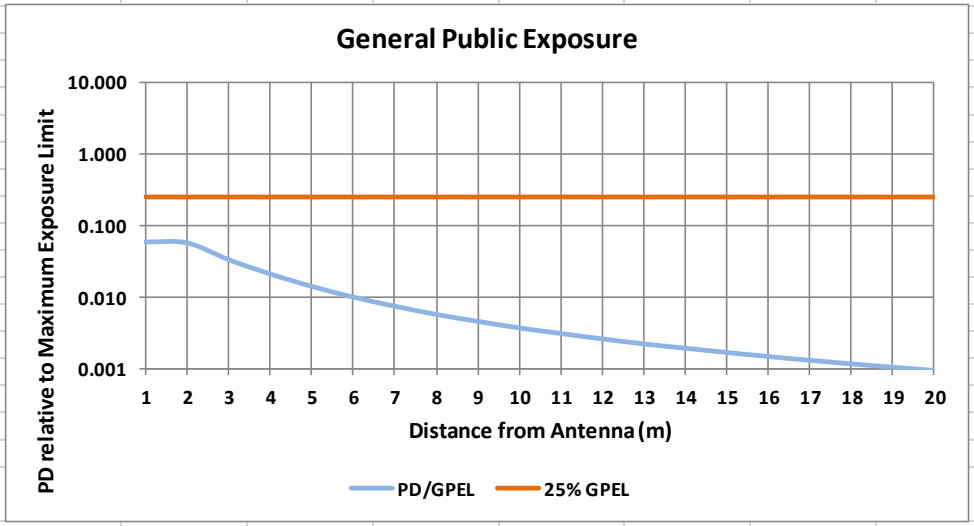
10 Appendix D: EMR Calculations

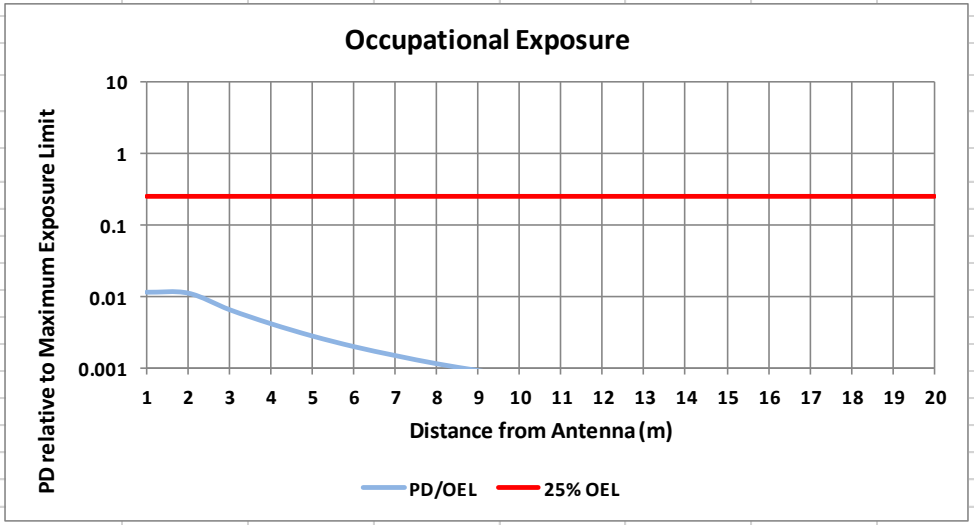
10.1 VHF Crossed Yagi: Kepler

PD versus distance along ground

Antenna Location		Kepler-UHF
Freq	MHz	150
Transmitter Power	W	10
	dBW	10
Feeder loss	dB	0
EIRP	dBW	21.1
Antenna Type		Yagi
Antenna Model		YB6-62
Antenna Size	m	1
Antenna Gain	dBi	11.1
Polarisation		
Antenna Az Beamwidth	deg	56
Antenna El Beamwidth	deg	47
Tx Antenna Height	m	2.7
Measurement Ht (ag)	m	2
Antenna Boresight Elevation Angle	deg	5
Far Field Boundary	m	1

NZS 2772 Exposure Limits	Public	Occupational	
Max Limit	2.000	10.000	W/m^2
1/4 Max Limit	0.5000	2.500	W/m^2



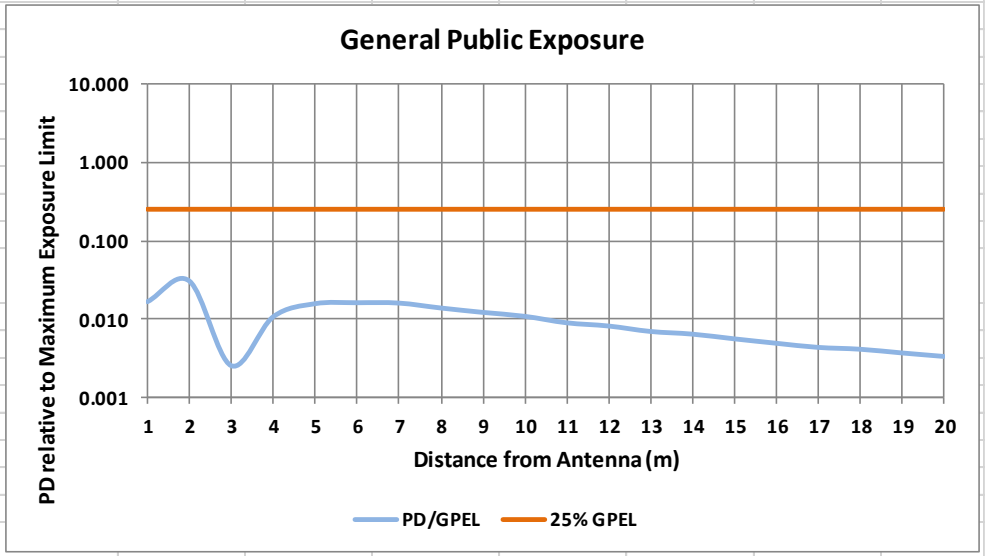


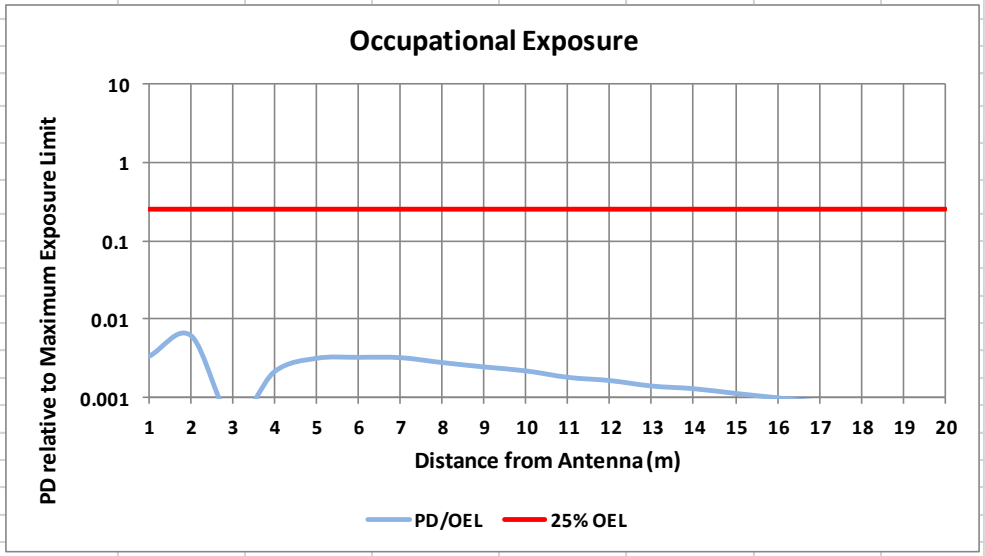
10.2 450MHz Crossed Yagi: Planet-1A/2A/2B/2C

PD versus distance along ground

Antenna Location		Planet-1A/2A/2B/2C
Freq	MHz	450
Transmitter Power	W	47
	dBW	16.72097858
Feeder loss	dB	0
EIRP	dBW	33.07097858
Antenna Type		Yagi
Antenna Model		UHF Circ Pol Yagi
Antenna Size	m	0.333333333
Antenna Gain	dBi	16.35
Polarisation		
Antenna Az Beamwidth	deg	27
Antenna El Beamwidth	deg	26
Tx Antenna Height	m	3.2
Measurement Ht (ag)	m	2
Antenna Boresight Elevation Angle	deg	5
Far Field Boundary	m	0.333333333

NZS 2772 Exposure Limits	Public	Occupational	
Max Limit	2.250	11.250	W/m^2
1/4 Max Limit	0.5625	2.813	W/m^2



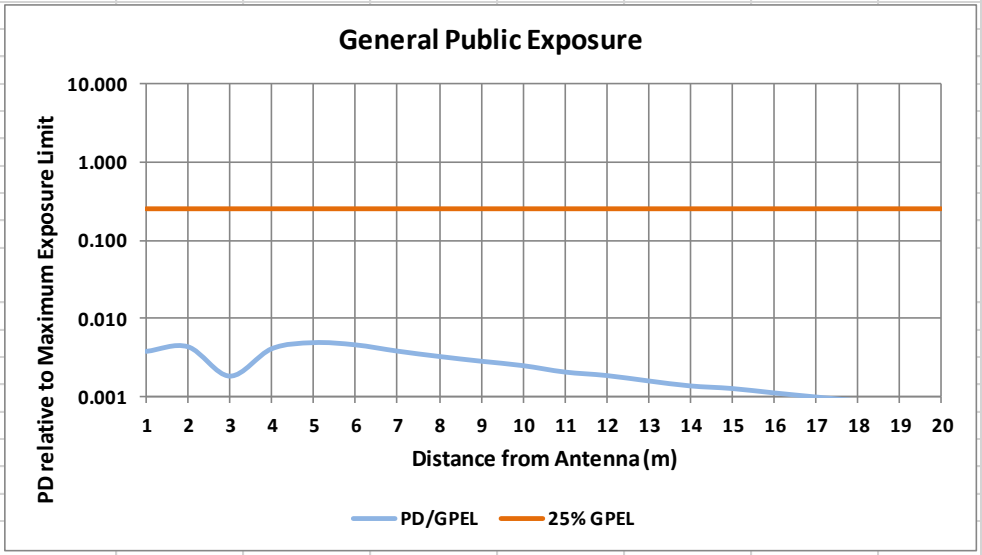


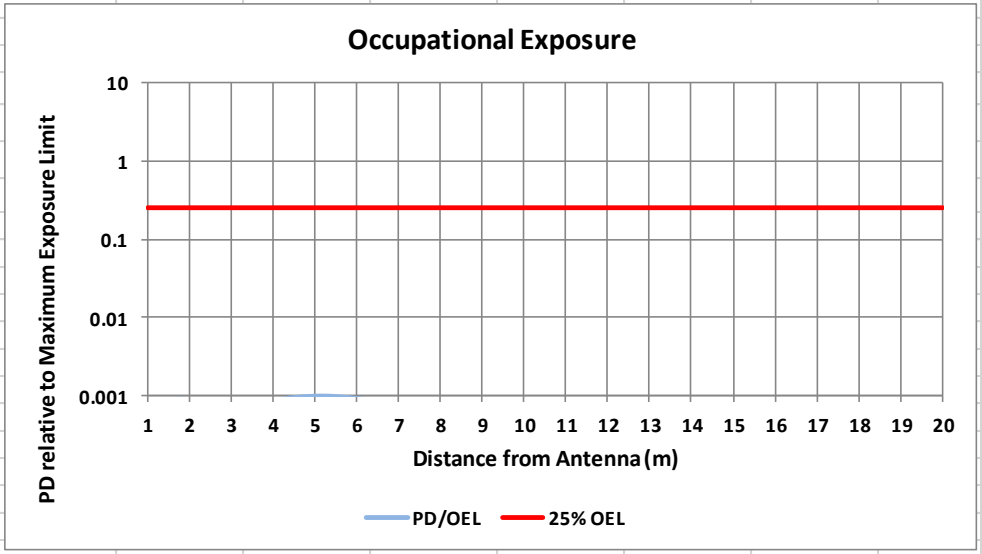
10.3 900MHz Crossed yagi: AWA-3 (Swarm)

PD versus distance along ground

Antenna Location		AWA-3 (Swarm)
Freq	MHz	890
Transmitter Power	W	20
	dBW	13.01029996
Feeder loss	dB	2.36
EIRP	dBW	27.00029996
Antenna Type		Yagi
Antenna Model		UHF Circ Pol Yagi
Antenna Size	m	0.168539326
Antenna Gain	dBi	16.35
Polarisation		
Antenna Az Beamwidth	deg	27
Antenna El Beamwidth	deg	26
Tx Antenna Height	m	3
Measurement Ht (ag)	m	2
Antenna Boresight Elevation Angle	deg	5
Far Field Boundary	m	0.168539326

NZS 2772 Exposure Limits	Public	Occupational	
Max Limit	4.450	22.250	W/m^2
1/4 Max Limit	1.1125	5.563	W/m^2





10.4 Omni: Swarm1/2/5

Parameters	value	units	
Antenna Length:	0.18	m	
Antenna Gain	2.00	dBi	
Transmit Power:	40	dBm	
	10.00	W	
Transmit EIRP	12.00	dBW	
Frequency:	900	MHz	
Wavelength:	0.333	m	
Far Field:			
Far Field Boundary:	0.1944	m	
Far Field Boundary: Power Density	33.3732	W/m^2	
Power Density:			
Distance from Antenna (GPEL)	**1.1**	m	
Far Field	1.1243	W/m^2	
Near Field	24.5020	W/m^2	
Calculated Field	1.1243	W/m^2	
Distance from Antenna (OEL)	**0.5**	m	
Far Field	5.6252	W/m^2	
Near Field	54.8060	W/m^2	
Calculated Field	5.6252	W/m^2	
NZS 2772	**Public**	**Occupational**	
Max Limit	4.500	22.500	W/m^2
1/4 Max Limit	1.1250	5.625	W/m^2

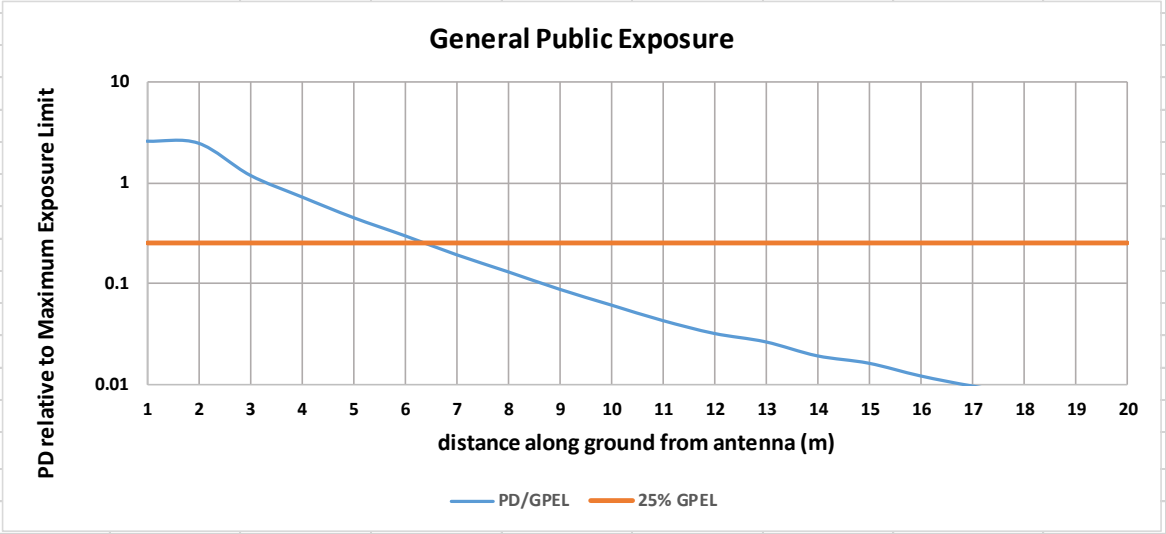
10.5 Patch: Swarm3/4

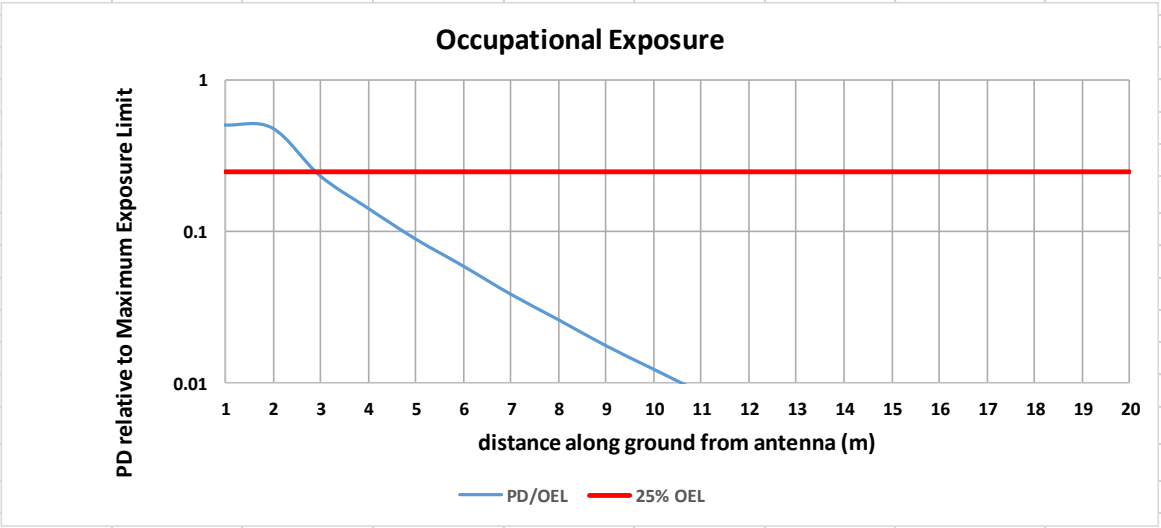
Parameters	value	units	
Antenna Dimensions:			
Height	0.10	m	
Width	0.10	m	
Antenna Beamwidth			
Horizontal	180	deg	
Vertical	180	deg	
Antenna Gain	5	dBi	
Transmit Power:	40	dBm	
	10.00	W	
Transmit EIRP	15.00	dBW	
Frequency:	900	MHz	
Wavelength:	0.333	m	
Far Field:			
Far Field Boundary: Distance	0.12	m	
Far Field Boundary: Power Density	174.7542	W/m^2	
Power Density:			
Distance from Antenna (GPEL)	**1.50**	m	
Far Field	1.12	W/m^2	
Near Field	21.28	W/m^2	
Power Density:	1.1249	W/m^2	
Distance from Antenna (OEL)	**0.67**	m	
Far Field	5.64	W/m^2	
Near Field	47.63	W/m^2	
Power Density:	5.6353	W/m^2	
NZS 2772	**Public**	**Occupational**	
Max Limit	4.500	22.500	W/m^2
1/4 Max Limit	1.125	5.625	W/m^2

10.6 S Band: AWA-1/AWA-4/KSAT-1 (SpaceX)/KSAT-2/KSAT-3/KSAT-4/Leaf-1/Planet-1/Planet-2/Spaceflight-1

PD versus distance along ground			
Antenna Location:	AWA-1/AWA-4/KSAT-1 (SpaceX)/KSAT-2/KSAT-3/KSAT-4/Leaf-1/Planet-1/Planet-2/Spaceflight-1/Spire-1		
Transmitter:			
Freq	GHz	2.0500	
wavelength	m	0.1463	
Transmit Power:	W	63.0000	
	dBW	17.9934	
EIRP (dBW)	dBW	52.9934	
Parabolic Antenna Parameters:			
Dia	m	3.7000	
Taper		3	
Antenna Gain(dBi)	dBi	35.0000	
Efficiency	%	50.12%	
Far Field:			
Dist to FF (D_FF)	m	187.0967	
PD:	W/m^2	0.4529	
	mW/sqcm	0.0453	
	dBuW/sqcm	16.5600	
Near Field:			
Dist to NF (D_NF):	m	46.7742	
	dB ref D_FF	-6.0206	
Max PD_on axis:			
Dist:	m	13.0968	
	dB ref D_FF	-11.5490	
PD:	W/m^2	30.1176	
	dBuW/sqcm	35.1875	
PD vs Ground Distance			
Antenna Centre (AG)	m	2.2	
Minimum Elevation Angle	deg	5	
Person height (P_ht)	m	2	

NZS 2772 Exposure Limits	Units	Public	Occupational
Max Limit	W/m^2	10.000	50.000
1/4 Max Limit	W/m^2	2.5000	12.500

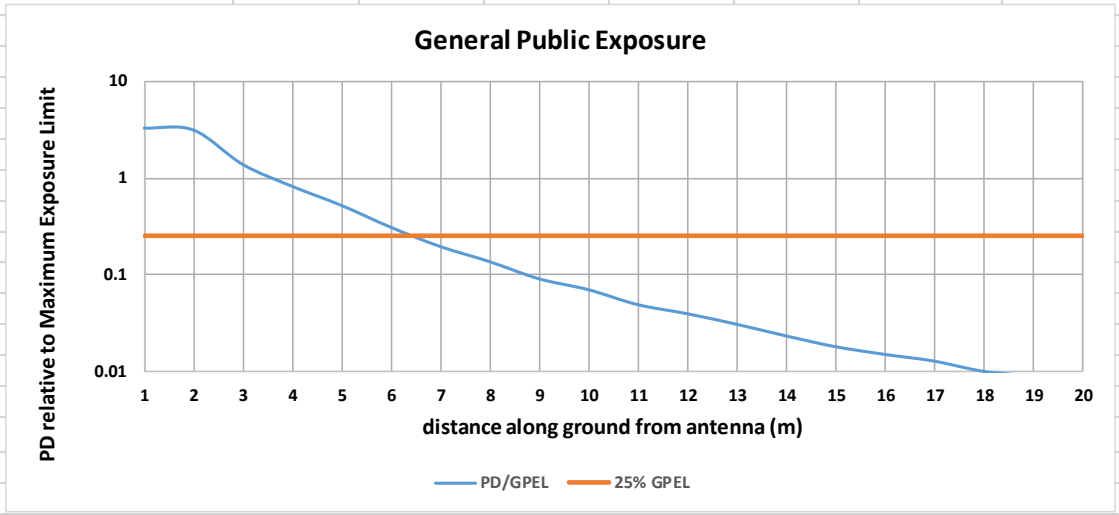


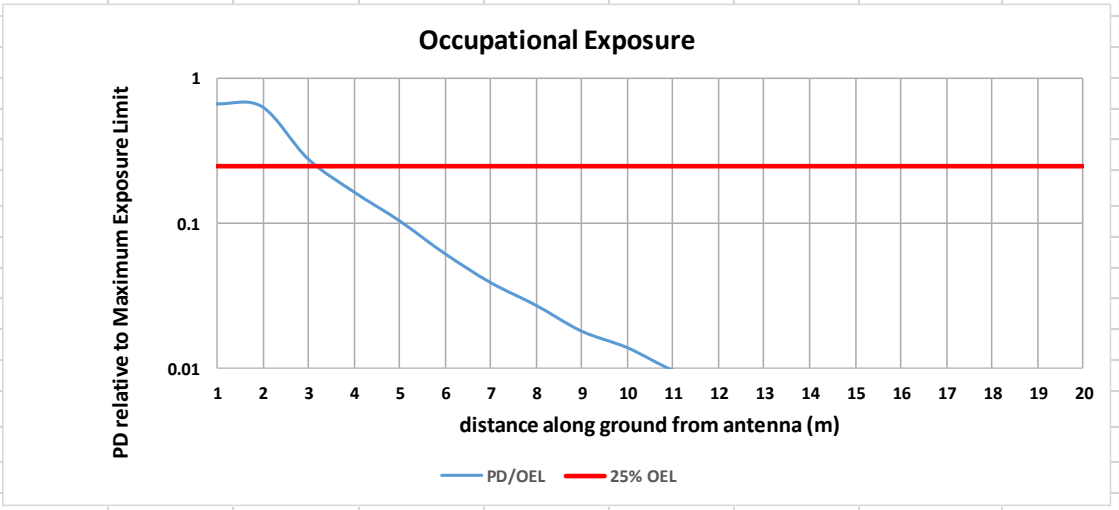


10.7 S Band: Spire-1

PD versus distance along ground			
Antenna Location:	Spire-1		
Transmitter:			
Freq	GHz	2.0500	
wavelength	m	0.1463	
Transmit Power:	W	63.0000	
	dBW	17.9934	
EIRP (dBW)	dBW	51.9934	
Parabolic Antenna Parameters:			
Dia	m	3.0000	
Taper		2	
Antenna Gain(dBi)	dBi	34.0000	
Efficiency	%	60.56%	
Far Field:			
Dist to FF (D_FF)	m	123.0000	
PD:	W/m^2	0.8324	
	mW/sqcm	0.0832	
	dBuW/sqcm	19.2032	
Near Field:			
Dist to NF (D_NF):	m	30.7500	
	dB ref D_FF	-6.0206	
Max PD_on axis:			
Dist:	m	8.6100	
	dB ref D_FF	-11.5490	
PD:	W/m^2	55.3531	
	dBuW/sqcm	37.8307	
PD vs Ground Distance			
Antenna Centre (AG)	m	2.2	
Minimum Elevation Angle	deg	5	
Person height (P_ht)	m	2	

NZS 2772 Exposure Limits	Units	Public	Occupational
Max Limit	W/m^2	10.000	50.000
1/4 Max Limit	W/m^2	2.5000	12.500

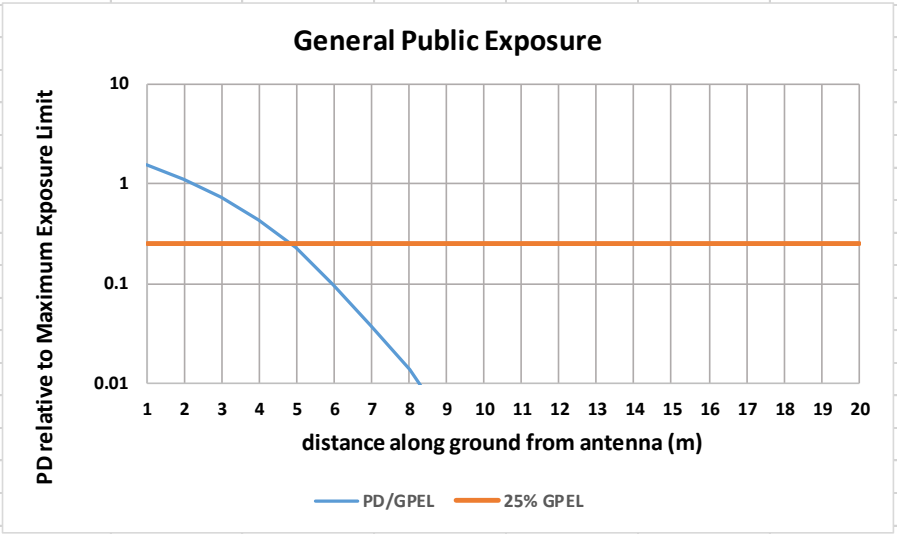


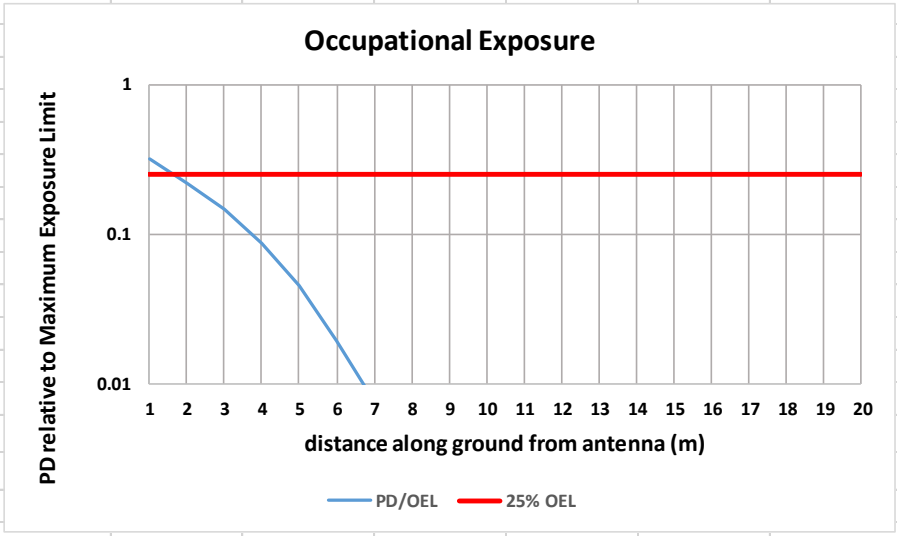


10.8 C Band: GlobalStar-1/2/3

PD versus distance along ground			
Antenna Location:	Global Star-1/2/3		
Transmitter:			
Freq	GHz	5.2000	
wavelength	m	0.0577	
Transmit Power:	W	300.0000	
	dBW	24.7712	
EIRP (dBW)	dBW	71.9712	
Parabolic Antenna Parameters:			
Dia	m	6.0000	
Taper		2.0000	
Antenna Gain(dBi)	dBi	47.2000	
Efficiency	%	49.16%	
Far Field:			
Dist to FF (D_FF)	m	1248.0000	
PD:	W/sqm	0.8044	
	mW/sqcm	0.0804	
	dBuW/sqcm	19.0548	
Near Field:			
Dist to NF (D_NF):	m	312.0000	
	dB ref D_FF	-6.0206	
Max PD_on axis:			
Dist:	m	87.3600	
	dB ref D_FF	-11.5490	
PD:	W/sqm	53.4939	
	dBuW/sqcm	37.6823	
PD vs Ground Distance			
Antenna Centre (AG)	m	3.3	
Minimum Elevation Angle	deg	10	
Person height (P_ht)	m	2	

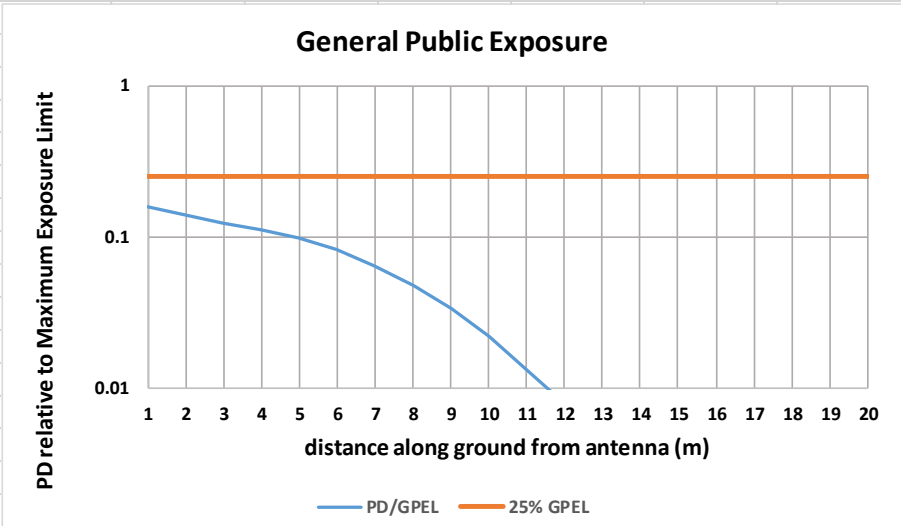
NZS 2772 Exposure Limits	Public	Occupational	
Max Limit	10.000	50.000	W/m^2
1/4 Max Limit	2.5000	12.500	W/m^2

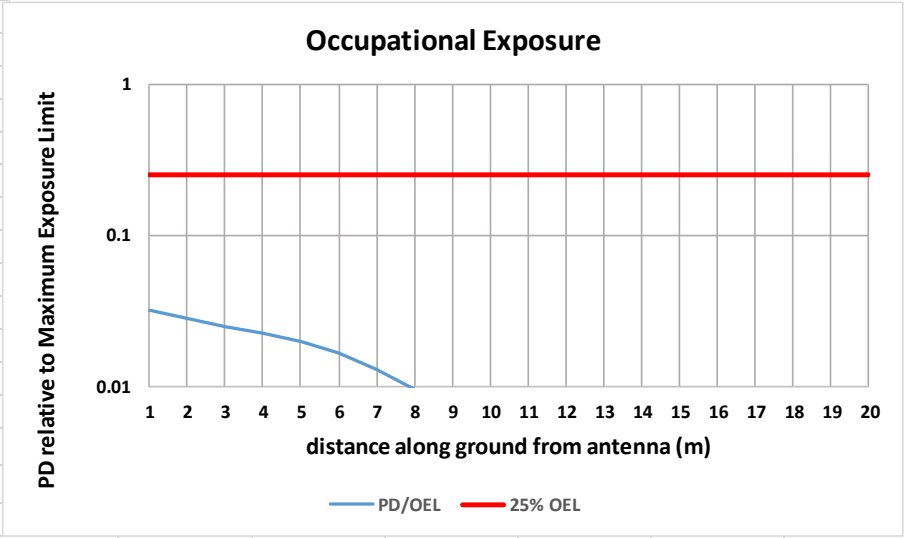




10.9 Ku Band: Kepler

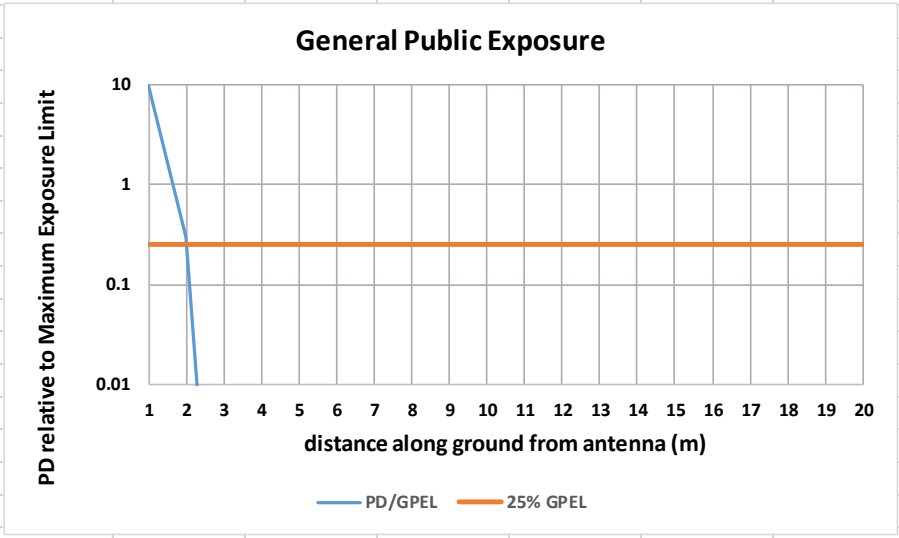
PD versus distance along ground			
Antenna Location:	Kepler		
Transmitter:			
Freq	GHz	14.2500	
wavelength	m	0.0211	
Transmit Power:	W	7.0000	
	dBW	8.4510	
EIRP (dBW)	dBW	56.8510	
Parabolic Antenna Parameters:			
Dia	m	3.4000	
Taper		2.0000	
Antenna Gain(dBi)	dBi	48.4000	
Efficiency	%	26.88%	
Far Field:			
Dist to FF (D_FF)	m	1098.2000	
PD:	W/sqm	0.0320	
	mW/sqcm	0.0032	
	dBuW/sqcm	5.0453	
Near Field:			
Dist to NF (D_NF):	m	274.5500	
	dB ref D_FF	-6.0206	
Max PD_on axis:			
Dist:	m	76.8740	
	dB ref D_FF	-11.5490	
PD:	W/sqm	2.1249	
	dBuW/sqcm	23.6728	
PD vs Ground Distance			
Antenna Centre (AG)	m	2.2	
Minimum Elevation Angle	deg	5	
Person height (P_ht)	m	2	
NZS 2772 Exposure Limits	**Public**	**Occupational**	
Max Limit	10.000	50.000	W/m^2
1/4 Max Limit	2.5000	12.500	W/m^2

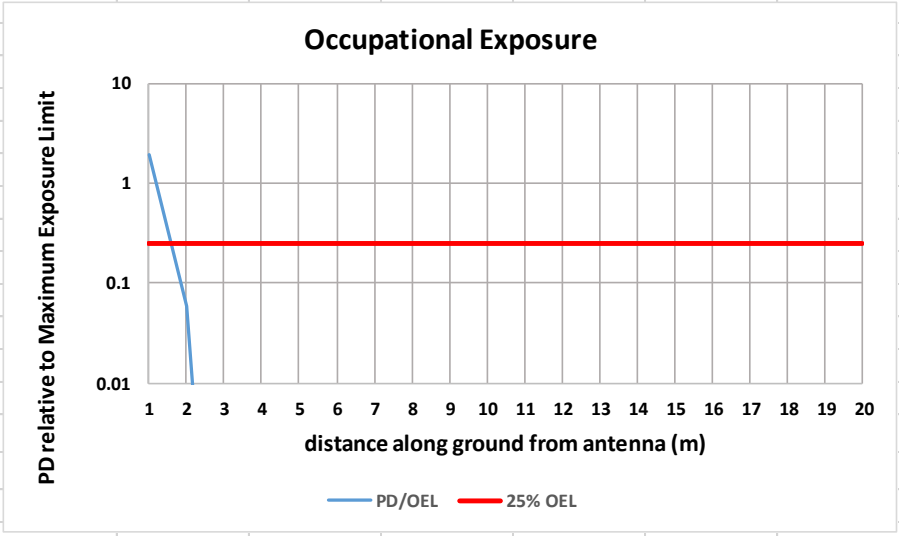




10.10 Ka Band: Starlink

PD versus distance along ground			
Antenna Location:	Starlink		
Transmitter:			
Freq	GHz	28.7500	
wavelength	m	0.0104	
Transmit Power:	W	50.0000	
	dBW	16.9897	
EIRP (dBW)	dBW	66.9897	
Parabolic Antenna Parameters:			
Dia	m	1.5000	
Taper		2.0000	
Antenna Gain(dBi)	dBi	50.0000	
Efficiency	%	49.03%	
Far Field:			
Dist to FF (D_FF)	m	431.2500	
PD:	W/sqm	2.1394	
	mW/sqcm	0.2139	
	dBuW/sqcm	23.3030	
Near Field:			
Dist to NF (D_NF):	m	107.8125	
	dB ref D_FF	-6.0206	
Max PD_on axis:			
Dist:	m	30.1875	
	dB ref D_FF	-11.5490	
PD:	W/sqm	142.2734	
	dBuW/sqcm	41.9305	
PD vs Ground Distance			
Antenna Centre (AG)	m	1.7	
Minimum Elevation Angle	deg	25	
Person height (P_ht)	m	2	
NZS 2772 Exposure Limits	**Public**	**Occupational**	
Max Limit	10.000	50.000	W/m^2
1/4 Max Limit	2.5000	12.500	W/m^2





10.11 Uncertainty of the RF field assessment (Appendix D of AS/NZS 2772:2:2016

Source of Uncertainity (input quantity)	unit	Probability Distribution	Uncertainty Range Type	Uncertainty Range Value	Divisor (d)	Sensitivity Coefficient c	ui	$c_i^2 * u_1^2$
Variation in power of the RF Transmitter from its nominal level	dB	Triangular	a	0.5	2.44949	1	0.204124	0.04
Maximum Antenna gain	dB	Normal	u	0.3	1	1	0.3	0.09
Analysis technique	dB	Normal	u	1.5	1	1	1.5	2.25
						Combined standard uncertainty (dB)		1.54
						Coverage factor for 95% CI		1.64
						Expanded uncertainty(dB)		**2.53**

11 Appendix E: References

10. On Axis Power Density Calculations Appendix E AS/NZS2772.2-2016
11. Off Axis Power Density Calculations:
    Kizer, George M: Digital Microwave Communication: engineering point to point microwave systems. 2013 John Wiley and Sons Inc.
    Chapter 8 Microwave Antenna Theory Fig 8.16 and Appendix 8.A.1.
12. Recommendation ITU-T K.52: Guidance on complying with limits for human exposure to electromagnetic fields.
13. NZS 2772: Part 1:1999 Radiofrequency Part 1 - Maximum Exposure Levels - 3kHz to 300GHz.